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THE OUTLOOK FOR CONVENTIONAL PETROLEUM RESOURCES*

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Conventionally produced petroleum is not a long-term energy resource for the world. The known and prospective conventional petroleum accumulations of the world are geologically limited. Petroleum is a replenishable resource only in terms of the geologic time-scale. Current rates of consumption of petroleum liquids and natural gas can only continue for several decades, given what we know about the size of the recoverable resource base.

Even though conventionally produced petroleum liquids and natural gas are not a long-term energy resource for the world, considering the prospects for them is both an appropriate and crucial task for a conference organized to explore long-term energy possibilities. Conventionally produced petroleum liquids and natural gas provide more than half of the energy used in the world today. The extent to which they will be available in the decades ahead is the most important factor determining the timing and scope of the inescapable transformation which will have to occur in world energy production and consumption.

This paper addresses the prospects for conventionally produced petroleum. This includes crude oil, natural gas liquids, and natural gas produced from accumulations where some commercial production can occur without injection or fracturing. It excludes petroleum liquids produced from tar sands, oil shale, coal, and biomass. It excludes natural gas produced from coal, shales, tight (microdarcy

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permeability) sandstones, and landfills. In some cases, the dividing line between the conventional and nonconventional is fuzzy, for example, between conventionally produced heavy crude oil and some tar sands or between natural gas production from low and very low permeability sandstones. These, however, are rare enough to make the distinction a workable one in practice.

A survey of the outlook for conventional petroleum resources could take any one of several directions. For example, it could summarize an individual world petroleum resource assessment or it could critically survey existing assessments, in both cases focusing on the *results* of one or more resource assessments. This paper will focus primarily on general *approaches* to the problem of world petroleum resource assessment. Because differences in *how* people think about petroleum resources are the main factor in explaining differences in *what* they think, addressing general approaches promises to be more conducive to clear thinking than merely discussing results. After a brief overview of known conventional world petroleum resources, this paper will discuss three key points to consider in evaluating the outlook for world petroleum resources. Using that discussion as a point of reference, three common misconceptions in petroleum resource assessment will then be described and critiqued. The paper will conclude with a brief summary of the outlook for conventional petroleum resources.

As of the end of 1978, approximately 1.1 trillion barrels ($175 \times 10^9 m^3$) of petroleum liquids and 3.7 quadrillion cubic feet

($105x10^{12}m^3$) of natural gas had been discovered and made recoverable in the world (Table 1). Approximately 424 billion barrels ($67.4x10^9m^3$) and 1030 trillion cubic feet ($29.2x10^{12}m^3$) of these amounts have been produced, leaving proved and probable reserves of 676 billion barrels ($107.4x10^9m^3$) and 2670 trillion cubic feet ($75.6x10^{12}m^3$). The known conventional recoverable resources of petroleum liquids are highly concentrated in three regions of the world: the Middle East, North America, and the Soviet Union. Together, these three regions contain slightly more than 80 percent of total known conventional resources. The Middle East contains nearly half of the world's known recoverable resources of petroleum liquids. The Soviet Union contains slightly more than one-third of the world's known recoverable resources of natural gas. This concentration by region provides an appropriate introduction to the first and most important point about world petroleum resources, namely, *petroleum resources are highly concentrated in a small number of sedimentary provinces.*

The existence of hydrocarbons in sedimentary areas is a common phenomenon. There are approximately 600 sedimentary provinces in the world, the exact number depending on how one chooses to define an individual province. Exploratory drilling has occurred in more than 400, resulting in discoveries of producible accumulations at current world prices in nearly 240 (60%). Indications of hydrocarbons have been encountered in most of the remaining 160. The near ubiquity of the existence of hydrocarbons in the sedimentary areas of the world should not, however, blind us to the more important

Table 1

KNOWN CONVENTIONAL RECOVERABLE RESOURCES[a] OF PETROLEUM LIQUIDS AND NATURAL GAS IN THE WORLD BY REGION AS OF DECEMBER 31, 1978

Region	Petroleum Liquids 10^9 bbls.	Petroleum Liquids ($10^9 m^3$)	Natural Gas 10^{12} ft^3	Natural Gas ($10^{12} m^3$)
North America	242.2	(38.5)	930	(26.3)
South America	69.9	(11.1)	126	(3.6)
Western Europe	24.4	(3.9)	203	(5.8)
Soviet Union/ Eastern Europe	115.5	(18.4)	1,275	(36.1)
Africa	74.8	(11.9)	204	(5.8)
Middle East	523.3	(83.2)	788	(22.3)
Asia/Oceania	50.3	(8.0)	174	(4.9)
World Total	1,100.4	(174.9)	3,700	(104.8)

[a] Known recoverable resources are defined as cumulative production plus proved and probable reserves.

fact that accumulations of conventional petroleum on a significant scale are a statistically rare event.

Measures of significance are of course subjective, depending on the perspective that one chooses. Because this conference addresses long-term energy resources for the world, an appropriate measure of significance is current world consumption of petroleum liquids and natural gas. In 1978, world consumption of petroleum liquids was slightly more than 23 billion barrels ($3.7x10^9m^3$). World consumption of natural gas was slightly less than 54 trillion cubic feet ($1.5x10^{12}m^3$). Using the standard equivalency conversion of 6000 cubic feet per barrel, total world consumption of conventional petroleum was approximately 32 billion barrels ($5.1x10^9m^3$) of liquid and liquid-equivalent petroleum resources. The latter number provides a useful standard of significance for world energy resources.

After more than a century of petroleum exploration covering nearly all of the prospective areas of the world, only ten provinces containing oil and gas equal to a year or more of current world consumption have been discovered (Table 2). Those ten provinces contain 72 percent of all the conventional petroleum liquids and 61 percent of all the natural gas known to be recoverable. Only two provinces--the Arabian-Iranian and the West Siberian--are known to contain more petroleum resources than is currently consumed in two years. The Arabian-Iranian province clearly dominates, with recoverable resources equivalent to more than twenty years of current world consumption. The West Siberian province has recoverable

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THE MAJOR PETROLEUM PROVINCES OF THE WORLD

Province	Known Recoverable Resources as of 12-31-78			
	Petroleum Liquids		Natural Gas	
	10^9 bbls.	$(10^9 m^3)$	10^{12} ft^3	$(10^{12} m^3)$
1. Arabian-Iranian	523.0	(83.1)	c.768.0	(21.7)
2. West Siberian (USSR)	c. 37.0	(5.9)	c.780.0	(22.1)
3. Volga-Ural (USSR)	c. 40.0	(6.4)	c.108.0	(3.1)
4. Maracaibo (Venezuela)	41.2	(6.5)	54.0	(1.5)
5. Mississippi Delta (USA)	21.5	(3.4)	169.4	(4.8)
6. Permian (USA)	30.0	(4.8)	73.9	(2.1)
7. Texas Gulf Coast-Burgos (USA-Mexico)	18.4	(2.9)	138.0	(3.9)
8. Reforma-Campeche (Mexico)	36.4	(5.8)	25.2	(0.7)
9. Sirte (Libya)	30.0	(4.8)	31.8	(0.9)
10. Alberta (Canada)	16.3	(2.6)	94.2	(2.7)
(Super-Province) Subtotals	793.8	(126.2)	2,242.5	(63.5)
11. Amarillo-Anadarko-Ardmore (USA)	9.8	(1.6)	116.4	(3.3)
12. Niger Delta (Nigeria-Cameroon)	20.5	(3.3)	51.0	(1.4)
13. Northern North Sea	20.0	(3.2)	40.2	(1.1)
14. Triassic (Algeria)	10.8	(1.7)	90.0	(2.5)
15. E. Texas-Arkla (USA)	15.2	(2.4)	50.1	(1.4)
16. N. Caucasus-Mangyshlak (USSR)	c. 11.8	(1.9)	c. 54.0	(1.5)
17. Netherlands-NW Germany	2.0	(0.3)	93.0	(2.6)
18. Eastern Venezuela (Venezuela-Trinidad)	13.1	(2.1)	21.0	(0.6)
19. South Caspian (USSR)	c. 12.0	(1.9)	c. 15.0	(0.4)
20. North Slope (USA)	9.9	(1.6)	26.0	(0.7)
21. San Joaquin (USA)	11.6	(1.8)	12.0	(0.3)
22. Tampico-Misantla (Mexico)	10.7	(1.7)	9.0	(0.3)
23. Amu Daryu (USSR)	0.5	(0.1)	c. 60.0	(1.7)
24. Appalachian (USA)	4.0	(0.6)	38.4	(1.1)
25. Los Angeles (USA)	8.6	(1.4)	7.2	(0.2)
26. Murgab (USSR)	0.	(0.)	c. 57.0	(1.6)
27. Dnepr-Pripyat (USSR)	2.0	(0.3)	c. 45.0	(1.3)
28. Sung-liao (China)	c. 8.5	(1.4)	c. 6.0	(0.2)

Table 2 (continued)

Province	Known Recoverable Resources as of 12-31-78			
	Petroleum Liquids		Natural Gas	
	10^9 bbls.	$(10^9 m^3)$	10^{12} ft^3	$(10^{12} m^3)$
29. Central Sumatra (Indonesia)	9.0	(1.4)	c. 1.2	(*)
30. Timan-Pechora (USSR)	c. 4.0	(0.6)	c. 27.0	(0.8)
(Major Province Subtotals)	184.0	(29.3)	819.5	(23.2)
Super and Major Provinces	977.8	(155.5)	3,062.0	(86.7)
World Total	1,100.4	(174.9)	3,700.0	(104.8)

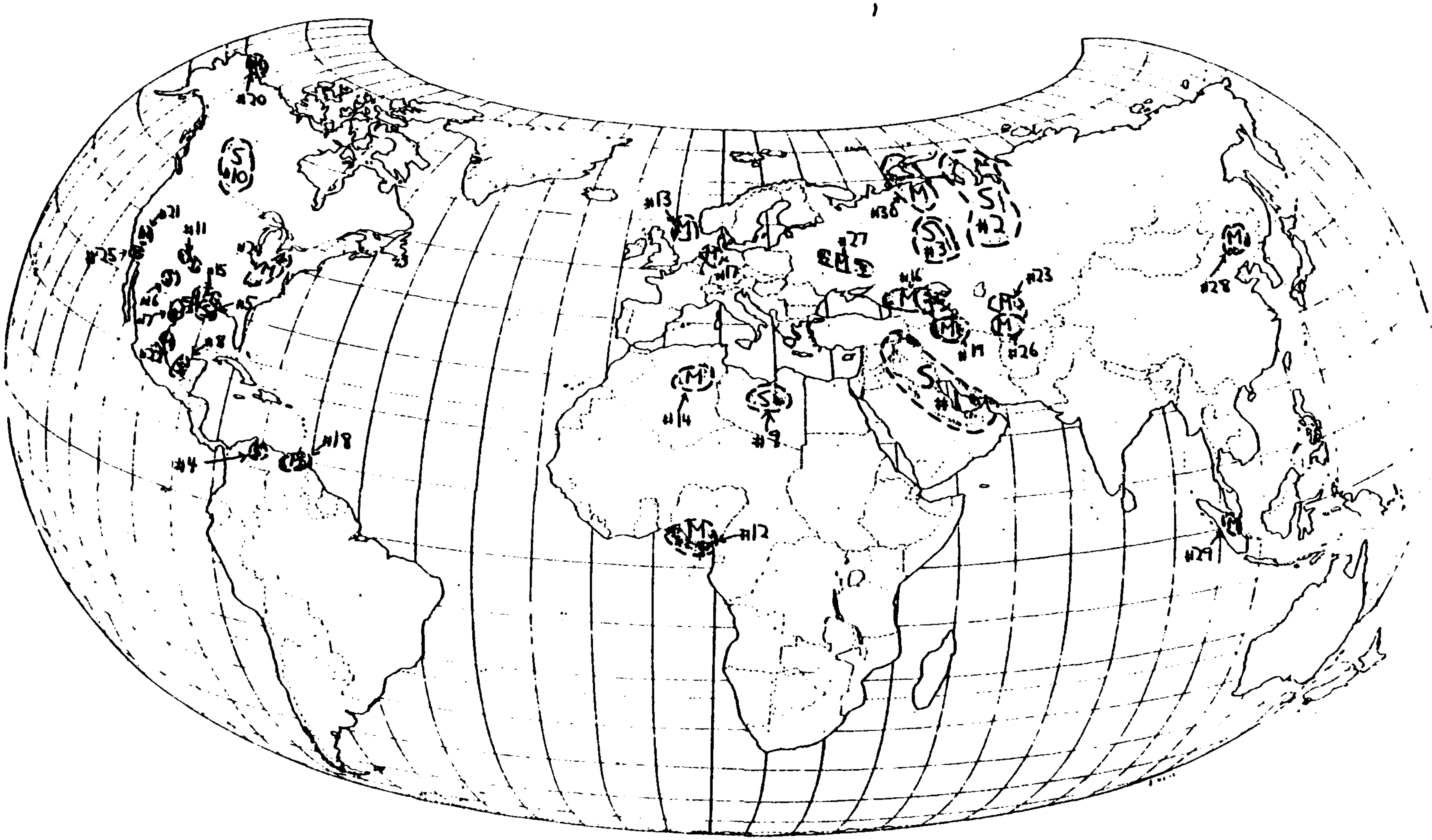
resources equivalent to slightly more than five years current world consumption. Together the two contain 51 percent of known recoverable resources of petroleum liquids and 42 percent of the natural gas resources. (Combining the Mississippi Delta province with the Texas Gulf Coast-Burgos province, as some do, would create a Gulf Coast province with resources equivalent to nearly three years current world consumption.) Because of their significance, these ten provinces clearly merit the designation as *super-provinces*.

A relaxation of the standard of significance further confirms the point. There are only twenty provinces with conventional petroleum resources equivalent to three to twelve months of current world petroleum consumption (8-32x10^9 barrels). These twenty provinces contain another 17 percent of known conventional petroleum liquids resources and 22 percent of known natural gas resources. The thirty largest provinces contain 89 percent of the known recoverable petroleum liquids and 83 percent of the known recoverable natural gas provinces. The other 210 provinces with producible accumulations contain only 11 percent of the petroleum liquids and 17 percent of the natural gas, over half of which are in 35 or so provinces with 2 to 8 billion barrels liquid and liquid-equivalent resources each. Thus, nearly all of the world's conventional petroleum resources are concentrated in only 15 percent of the explored sedimentary provinces.

Two interrelated aspects of the geographical distribution of the most significant provinces are noteworthy. First, they are concentrated in two arcs, one in each hemisphere. In the Eastern

Hemisphere, the most significant provinces are concentrated in an arc traversing North Africa, the Middle East, and the central Soviet Union. In the Western Hemisphere, the most significant provinces are concentrated in an arc traversing Venezuela, the western Gulf of Mexico, the central United States, and western Canada (Figure 1). All of the super-provinces and half of the major provinces are found within these two arcs. Secondly, not one of the thirty most significant provinces lies south of the equator. Central Sumatra straddles it. The Niger Delta, the Maracaibo Basin, and the Eastern Venezuela Basin are between 0° and 10° N latitude. Twenty-three of the thirty are between 20° and 60° N latitude.

The great variation in the distribution of petroleum resources by province and region should not be surprising. The sedimentary provinces of the world differ widely in sedimentary volume. More importantly, they differ even more in their geologic history and characteristics. For large accumulations of petroleum to exist, several conditions must have existed in an appropriate temporal and spatial relationship with each other. Sufficient organic material must have been produced, accumulated and preserved. This material must be buried to a depth where sufficient temperature and pressure exist to generate petroleum. After the petroleum is generated, it must be expelled from the source rock into permeable carrier or reservoir rocks. Traps with porous and permeable reservoir rocks covered by impermeable sealing rocks must exist where the migrating petroleum can accumulate. These traps must not be breached after accumulation occurs (Meyerhoff, 1976; Tissot and Welte, 1978).



S - Super Province

M - Major Province

Figure 1. The Major Petroleum Provinces of the World

Where these conditions are met to a high degree, we encounter the major accumulations of the Middle East, West Siberia, or the provinces circling the western Gulf of Mexico. Where production of organic material was insufficient, where the organic material that was produced was oxidized, where unoxidized organic material was buried to an insufficient depth, where migration did not occur or occurred prior to the formation of traps, where reservoir rocks are poor or nonexistent, where sealing rocks did not exist, or where traps with petroleum accumulations were destroyed by subsequent erosion or tectonic activity, only negligible amounts of petroleum, if any, are likely to be found. Most provinces lie between the extremes of the optimal and the deficient. But significant concentrations of petroleum are found only where optimal or near-optimal conditions are found as well.

The second point to consider in evaluating conventional world petroleum resources is that *the world's oil and gas resources are highly concentrated in a small number of large fields.* Since petroleum exploration began, approximately 30,000 fields have been discovered. But more than 90 percent of these fields are insignificant as far as world petroleum resources are concerned. The 30 largest oil and gas fields discovered to date--those with ten billion barrels ($1.59 \times 10^9 m^3$) or more of liquid or liquid-equivalent recoverable resources--contain 475 billion barrels ($75.5 \times 10^9 m^3$) of petroleum liquids and 1124 trillion cubic feet ($31.8 \times 10^{12} m^3$) of

natural gas. In other words, just 0.1 percent of the known fields contain 43 percent of the petroleum liquids and 30 percent of the natural gas discovered to date. The 52 super-giant fields discovered to date--those with five billion barrels ($0.79 \times 10^9 m^3$) or more of liquid or liquid-equivalent recoverable resources--contain 569 billion barrels ($90.5 \times 10^9 m^3$) of petroleum liquids and 1500 trillion cubic feet ($42.5 \times 10^{12} m^3$) of natural gas, 52 percent and 41 percent, respectively, of the world's conventional oil and gas resources. The approximately 400 known giant fields--those with 500 million barrels ($79 \times 10^6 m^3$) or more of liquid or liquid-equivalent recoverable resources--contain approximately 850 billion barrels ($135.1 \times 10^9 m^3$) of petroleum liquids and 2600 trillion cubic feet ($73.6 \times 10^{12} m^3$) of natural gas, 77 percent and 70 percent, respectively, of the world's conventional oil and gas resources. The approximately 1400 known large fields--those with 50 to 500 million barrels ($8\text{-}79 \times 10^6 m^3$) of liquid or liquid-equivalent resources contain at least another 175 billion barrels ($27.8 \times 10^9 m^3$) of petroleum liquids and 750 trillion cubic feet ($21.2 \times 10^{12} m^3$) of natural gas. Thus, only 6 percent of the known fields contain over 93 percent of the known conventional petroleum liquids and over 90 percent of the known conventional natural gas resources of the world. (For the most recent treatment of the importance of giant oil fields, see Nehring, 1978.)

Significant petroleum fields and significant petroleum provinces are closely associated. The ten super-provinces contain 44 of the 52 super-giant fields. Six of the remaining eight are found in the

ten largest major provinces. The importance of the Arabian-Iranian and West Siberian provinces stems from the fact that they contain 30 and 7 super-giant fields, respectively. The Mississippi Delta and Texas Gulf Coast-Burgos provinces are unusual in that they are the only super-provinces with no super-giant fields, nothing resembling a super-giant field, and relatively few giant fields. But the former has more than 250 large and giant fields while the latter has 140 large and giant fields. The Niger Delta is the only other major province in which the known oil and gas resources are concentrated in large rather than giant fields.

The third key point is that *modern petroleum exploration is an efficient process*. Operationally, this means that if giant and large accumulations of petroleum exist in a sedimentary province, most will be found by the time 25 to 200 new field exploratory wells have been drilled in the province. This number is likely to be exceeded only when there is a very large number of potential large accumulations within the province or if the pattern of drilling within the province is shaped heavily by political or technological constraints. Exploration efficiency is the result of the geologic fact that most giant and large fields occur in obvious traps, that is, traps that are detectable prior to drilling (Klemme, 1973/1974); that improvements in geologic knowledge and exploratory technology are enabling the petroleum industry to locate these traps with increasing effectiveness; and that any rational exploration philosophy emphasizes drilling the largest prospects first in exploring a virgin province.

Intra-province exploration efficiency is particularly evident in those provinces in which exploration began since World War II. Nearly all of the giant fields discovered in major provinces were found in less than ten years after the initial giant field discovery (Klemme, 1971; Nehring, 1978, p. 37). In the provinces opened up since 1965, the process may even have accelerated, given the high success rates and rapid rates of discovery witnessed in the Reforma-Campeche, Oriente, Southern North Sea, Northern North Sea, Cambay, Gippsland, Dampier, and Mahakam Delta provinces and subprovinces.

A recent development of the past ten to fifteen years appears to be a marked increase in inter-province exploration efficiency. Geological investigations prior to exploratory drilling are becoming more and more capable of distinguishing between geologically favorable and unfavorable conditions. Geologic knowledge and exploratory technology have progressed to the point where only a handful of exploratory wells may be necessary to indicate whether a province is likely to contain significant amounts of petroleum. If a few wells encounter unfavorable geologic conditions of regional significance, as has occurred in the Gulf of Alaska and most of the East African coastal provinces, those wells are sufficient to indicate that the entire province will not be a major source of petroleum.

These three points considered together provide a powerful means of understanding the present status of world petroleum resources and for predicting the ultimate conventional petroleum resources of

the world. Because only major and super-provinces make any appreciable difference, the task of world petroleum resource assessment is predominantly one of estimating future discoveries and reserve growth in known major provinces, of determining which other producing provinces have a chance of becoming major provinces with further discoveries and development, and of assessing which unexplored provinces have a meaningful probability of becoming major provinces. Because most of the oil and gas is found in giant and large fields, the assessment of unexplored provinces can focus on whether and how many large traps exist in a province if other conditions are favorable for petroleum accumulation. Because modern petroleum exploration is an efficient process, resource assessment in known producing provinces can focus on known field-size distributions, those areas of a province in which past exploration has been constrained for technological or political reasons, and the possibilities of less obvious traps within the province.

The implications of these three facts for conventional world petroleum resource assessment are not favorable. The Arabian-Iranian, West Siberian, and Reforma-Campeche provinces are the only super-provinces that are likely to have several giant field discoveries in the future. The Amarillo-Anadarko-Ardmore, Niger Delta, Northern North Sea, and Triassic provinces are the only major provinces with a good probability of becoming super-provinces. The South Caspian, North Slope, Tampico-Misantla, and Timan-Pechora

provinces have a low probability of becoming super-provinces. None of the eight appears to have a potential for becoming more than just a minimal super-province. Of the nonmajor producing provinces, only six--Lena-Vilyuy (USSR), Illizi-Ghadames (Algeria-Libya), Suez (Egypt), North China and Szechwan (China), and Kutei (Indonesia)--appear to have the potential to become major provinces. Of the provinces that are unexplored or are only lightly explored there are probably no more than a dozen with the potential to become major provinces, including the Labrador Shelf, Beaufort Sea/Mackenzie Delta, and Sverdrup Basin (Canada), the Sabinas Basin (Mexico), the Gulf of Venezuela (Venezuela), the Malvinas Basin (Argentina-U.K.), the Norwegian Coastal Basin, the Lena-Anabar and East Siberian Sea provinces (USSR), and the East China Sea province (China). Currently the Beaufort Sea/Mackenzie Delta province is the only one of these that has a reasonable probability of becoming a super-province. Ultimately, of the world's 600 sedimentary provinces, no more than 40 to 45 will be major provinces (including 12 to 18 super-provinces.

During the past decade, several attempts have been made to evade the implications of these facts. These attempts have had enough surface plausibility to mislead both the political leadership and the public of many countries as to the true petroleum supply situation. But they can readily be shown to lack scientific support.

The first of these misconceptions is that *sedimentary volume (or area) is a useful indicator of petroleum potential* (Grossling, 1976).

The basic argument from this premise is that a substantial proportion of the world's sedimentary volume (or area) is still unexplored or lightly explored, particularly in the less-developed countries, and that with extensive drilling its full promise will be revealed. The argument gains plausibility from the fact that some of the world's most significant provinces, specifically the Arabian-Iranian and West Siberian, are also among the largest in sedimentary volume. However, sedimentary volume is only a minimally necessary condition for petroleum accumulation. The characteristics of the sediments are vastly more important than mere volume for explaining petroleum accumulation, as indicated by the wide variations in known recovery per unit of sedimentary volume among basins (Klemme, 1977). Moreover, when applied to provinces that have at least been lightly explored, this argument ignores the extensive amount of information that can now be obtained about the petroleum prospects of a province from a small number of exploratory wells.

A second major misconception is that *significant amounts of oil remain to be discovered in small fields* (Wood, 1979). The argument is that because the most intensely drilled area of the world, the United States, has a significantly greater proportion of its known recoverable petroleum resources in nongiant fields, an intensive drilling effort in the rest of the world will result in the discovery of hundreds of billions of barrels in large and small fields. The argument is woefully ignorant of the important geologic differences

between most of the U.S. petroleum provinces and most of the provinces of the rest of the world. First, two of the three largest provinces in the U.S.--the Mississippi Delta and the Texas Gulf Coast--have atypical field size distributions. They and the Niger Delta are the only three major provinces in which the majority of the petroleum resources are found in large rather than giant fields. Secondly, most of the oil in small fields (less than 50 million barrels liquid or liquid-equivalents) in the United States is found in wholly Paleozoic provinces. Provinces of this age contain a large proportion of the petroleum found in the United States and a small proportion of that found in other countries of the world. (The most prominent examples of Paleozoic provinces elsewhere in the world--Volga-Ural, Alberta, and Timan-Pechora--appear to have roughly similar field size distributions as the Mid-Continent/Permian Basin area of the United States.) The distribution of petroleum resources by field size in the Mesozoic and Tertiary provinces of the United States (excluding the Gulf Coast) does not differ significantly from that of Mesozoic and Tertiary provinces elsewhere in the world. (For a detailed survey of the distribution of U.S. petroleum resources by field size, see Nehring, 1980a.) Third, on the other extreme of field sizes, the concentration of the petroleum resources of the Arabian-Iranian and West Siberian provinces in super-giant and giant fields with large drainage areas makes it extremely unlikely that significant amounts of petroleum will be found in small fields in either of these two provinces. The argument is plausible that discoveries

of small and large fields will be relatively more important in the future than they have been in the past. But there is no reason to expect major percentage increases in world petroleum reserves from this source.

The third major misconception is that *higher prices will result in substantial increases in world petroleum reserves.* The argument is that high prices will induce drilling in expensive environments and encourage the development of known but previously sub-economic resources. This argument is qualitatively correct, but quantitatively inaccurate. Because most oil and gas is found in large and giant fields and because nearly all large and giant fields have good to excellent reservoir characteristics, the costs of finding and producing most of the world's conventional oil and gas are less than 10 percent of the current world oil price (or less than U.S.$2.50. per barrel or barrel-equivalent). Higher prices only make a difference for recovery from fields with poor reservoir characteristics such as the Chicontepec area in Mexico, for enhanced oil recovery from some fields, for the discovery of very small fields, and for exploration and production in expensive environments such as the high latitude or deep water provinces (Nehring, 1980b). None of these categories appears to contain more than 10 percent of the world's ultimate petroleum potential. Most contain substantially less.

Considering the prospects for future discoveries and additional recovery in the known producing provinces and the prospects of

unexplored or lightly explored provinces, I estimate that ultimate conventional production of petroleum liquids will be between 1.6 and 2.0 trillion barrels ($254\text{-}318 \times 10^9 m^3$). Ultimate conventional production of natural gas will be between 5000 and 6500 trillion cubic feet ($142\text{-}184 \times 10^{12} m^3$). The majority of the increase from known recoverable resources of petroleum liquids is likely to come from additional recovery from known fields, not future discoveries. Although the increase from known to ultimate recoverable resources of natural gas is slightly less than the increase for petroleum liquids, the prospects for future natural gas discoveries, particularly in the Middle East and the Asiatic and Siberian provinces of the Soviet Union, are more favorable than the prospects for future oil discoveries. Future reserve growth from known natural gas fields will be only a minor proportion of future reserve additions. A major breakthrough in oil recovery technology could add as much as 0.5 trillion barrels ($80 \times 10^9 m^3$) to this prognosis. No other possibilities for larger conventional resources appear to have any plausibility.

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